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MOISTURE FEATURES OF THE CONVECTIVE BOUNDARY LAYER IN OKLAHOMA

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SUMMARY

Data from an instrumented 461m tower and rawinsonde balloons are analysed to determine the characteristics of the moisture field in the planetary boundary layer over central Oklahoma. In the mean, the lowest 94% of the sensibly adiabatic layer exhibits an effectively constant mixing ratio. Inferences as to the effectiveness of downward mixing through the top of the boundary layer are drawn.

1. INTRODUCTION

Thermal structure at midday in a convective field is well known and consists of three distinct regions (e.g. Konrad 1970). In immediate contact with the surface is a superadiabatic region several tens of metres thick. Above this is a sensibly adiabatic layer capped by a markedly stable layer. However, moisture distribution in these regions has never been studied in detail.

Data on the moisture stratification were collected in the vicinity of the National Severe Storms Laboratory instrumented WKY-TV tower in north Oklahoma City, Oklahoma, a relatively undeveloped gently rolling region. Dry- and wet-bulb temperature sensors are mounted at 89-5m, 265-5m, and 443-8m on the tower. A pressure sensor is located on the lowest and highest levels. The thermistors and barometers are accurate to within 0·2 degC and 0·05 kPa (0·5 mb). Wet-bulb sensor precision is not known. All instruments have response times of the order of 30 seconds so that the environment rather than microphysical perturbations is measured.

Readings were taken at 10-second intervals, and hourly average values of temperature and mixing ratio were recorded from 10 May 1974 through 1 November 1974. From 3 September 1974 to 1 November 1974, 10-second readings were stored. However, middle level mixing ratios were invalid until 29 September.

Rawinsondes were released from a site roughly 500 m north of the instrumented tower twice daily at approximately 1200 and 1500 local time from 14 April through 10 May and from 3 September through 31 October 1974. The data were reduced so that there were generally five rawinsondes data points within the tower layer. Maximum separation between observations was 2·5 kPa.

2. RELATIONSHIP BETWEEN VERTICAL MOISTURE STRUCTURE AND STABILITY IN THE TOWER LAYER

Mixing ratio (q) and potential temperature (θ) are both conserved for dry adiabatic (γ_d) ascent. Thus, it would be reasonable to expect that if the sensibly adiabatic layer arises from convective currents originating in the contact layer, the hydrolapse (-∂q/∂z) would be zero across the adiabatic layer. This concept was examined by computing hydrolapse dependence upon the temperature lapse rate. Thermal and moisture lapse rates across the two tower layers were computed for every 10-second observation. The mean and the standard deviation of the moisture lapse as a function of the stability for the lower and upper tower layers were plotted (Fig. 1(a) and (b)).

The diagrams for the two layers are quite similar except that extreme stabilities (γ < -3γ_d) with their tendency toward a moisture inversion (Moses et al. 1968) observed across the lower layer are not present over the upper layer. For layers having a stability between neutral and that characteristic of the moist convection regime, a strong decrease in moisture with height occurs. As the lapse rate approaches adiabatic, not only does the moisture lapse approach zero but the scatter around the mean value also decreases. At neutral stability the mean hydrolapse across the upper layer is 0·4 g kg⁻¹ km⁻¹ and across the lower one 0·7 g kg⁻¹ km⁻¹.

Care must be taken in interpreting these results since the variables are measured at arbitrary...
levels. Thus, the measured lapse rates do not necessarily represent the atmosphere's actual state. An indicated neutral or superadiabatic lapse rate only guarantees that some layer between the two measurement heights has a neutral or superadiabatic lapse rate. Because the surface-based superadiabatic layer often extends to heights above the lowest tower level (Warner and Telford 1967) many neutral or superadiabatic measurements actually were taken partially in the contact layer yielding hydrolapses not representative of well-mixed conditions. To compensate for this effect, a diagram including only observations when the lapse rate over both tower layers was the same, was prepared (Fig. 2). Although this drastically reduced the sample size, there were still over 5000 observations of an adiabatic lapse rate which show the same tendency as the previous plots. When the thermal lapse rate is adiabatic, the mean hydrolapse is 0.3 g kg$^{-1}$km$^{-1}$ and exhibits a minimum standard deviation. Since mixing ratios are measured only to the nearest 0.05 g kg$^{-1}$, the hydrolapse corresponding to adiabatic conditions is within instrument noise. Thus, when the atmosphere immediately above the contact layer is adiabatic, the mixing ratio is sensibly constant with height for at least the atmosphere's lowest 0.5 km.

3. **Comparison of Tower and Rawinsonde Measurements**

Hourly average values of tower temperature and mixing ratio, centred on balloon release times, were computed from the 10-second data. Interpolation of rawinsonde data to tower levels yielded values from the two separate systems. There was a total of 113 hours when temperature comparisons were possible and 69 hours when humidity comparisons could be made. All three tower levels are treated as independent data points.

The mean difference between the rawinsonde and tower temperature measurements is
0·37 degC. However, the root mean square (r.m.s.) difference was 0·75 degC and the standard deviation (σr) between the measurements was 0·65 degC. The mean difference of mixing ratio measurements was 0·39g kg⁻¹ with a r.m.s. difference of 0·82g kg⁻¹ and a standard deviation 0·72g kg⁻¹. However, since the mixing ratio value varies over an order of magnitude and the standard deviation is an absolute index, the representativity of these statistics is dubious. Since the response characteristics of the tower instrumentation are much better than those of the balloon package, it is assumed that most of the differences are caused by rawinsonde inaccuracies.

4. Moisture in the contact layer

Utilizing the standard deviation of temperature measurements computed by the comparison, the well-mixed thermal layer was defined from rawinsonde data as the lowest layer containing at least three data points having a maximum potential temperature spread of 0·92 degC (σT), and the difference between any potential temperature and the layer-mean less than 0·65 degC (σr). This technique was applied to all afternoon soundings which occurred under clear skies (no reported level with over 80% relative humidity).

Of 74 such soundings, six exhibited no thermally mixed layer, and fourteen others showed the adiabatic layer above a surface based inversion. The remaining 54 soundings showed the 'normal' superadiabatic contact layer capped by a sensibly adiabatic layer. For these normal soundings, the mean depth of the surface based superadiabatic layer is 128m. For the 17 days on which two good soundings were taken, the diurnal height change of the top of the contact layer appeared random (9 falls, 8 rises), so no conclusions can be drawn. This nonconsistency is not surprising since the depth of the superadiabatic layer depends upon the wind structure via the Richardson number (Webb 1958).

A moisture inversion was present with three of the normal soundings (6%). All others exhibited a strong moisture decrease with height through the contact layer. With the exception of these three cases, the mean hydrolapse across the superadiabatic contact layer was 17·3g kg⁻¹km⁻¹. The strength of this hydrolapse is shown by the fact that 47 of the 54 soundings (87%) that had a surface-based superadiabatic layer capped by a sensibly neutral layer had a hydrolapse of greater than 5g kg⁻¹km⁻¹ across the lowest layer.

5. Moisture over the entire thermally well-mixed layer

For the 54 normal soundings, the mean thickness of the thermally well-mixed layer was 932m. The top of the adiabatic layer consistently increased between the first and the second sound-
ing of the day with a mean increase of 332m between the 1200 and 1500 soundings on the 17 paired sounding days.

The 'well-mixed' moist layer was arbitrarily defined as the lowest layer across which the mixing ratio varied by less than 10% from its layer mean value and in which the mixing ratio variation between levels was less than 10% of the lower level value. Applying this criterion to the 54 soundings, a low-level well-mixed layer was found in 52 cases. One of the soundings which failed to have such a layer exhibited a strong moisture inversion with maximum mixing ratio at 176m; the other was very dry with mixing ratios of less than 3g kg⁻¹ above the surface.

The remaining 52 soundings indicated that the well-mixed moist layer was 877m deep. On all but two of the paired-sounding days, the depth increased during the early afternoon (mean increase of 325m). Of the 52 samples, the well-mixed moist layer and the adiabatic layer had the same depth 17 times. In six cases the moist layer was slightly thicker than the thermal one. For the entire sample, the mean quotient of depths of the moist to the thermal layer was 0.94. For the 29 cases where the moist layer was thinner than the thermal one, the value was 0.81.

If the thermal layer were exactly adiabatic, drying at the top of the well-mixed thermal layer would produce an unstable situation; however, the allowable variation of 0·65 degC of a measured potential temperature from the layer mean enables the moisture decrease to occur while static stability is maintained.

6. IMPLICATIONS

The adiabatic layer arises from two effects: solar surface heating and internal redistribution of heat by entrainment of capping potentially warmer air into the boundary layer. Because the only moisture source generally present is at the earth's surface, the well-mixed moist layer must arise from moisture transfer upward from the contact layer. Since the upward transfer mechanisms for excess surface heat and water vapor are virtually identical (Dyer 1967), the quotient of heights of the well-mixed moist and thermal layers should indicate the importance of mixing downward through the inversion.

Carson (1973), by means of an energy budget analysis, showed that the ratio of the depth of the layer affected only by thermals rising out of the contact layer (ζ) to that of the adiabatic layer (h) is related to the ratio (A) of the downward heat flux through the inversion to that out of the contact layer by \( R = \frac{\zeta}{h} = 1 - A/(1 + 2A) \). Theoretical estimates of A are available in the literature.

Ball (1960) hypothesized that the upward flux from the surface equalled the downward flux through the inversion; this forces A to be unity and R to be 2/3. If no entrainment through the inversion is allowed (Lilly 1968), A is zero and R equals 1. Carson, from an examination of the 1953 O'Neill, Nebraska, data found that A varied from zero to 1/2 causing R to vary from 1 to 3/4.

Our analysis of Oklahoma data, based upon the ratio of the moist to thermal boundary layer, agrees quite well with that of Carson. 33% of the sample showed Lilly's minimum entrainment condition (A = 0), while 56% of the sample showed an active entrainment with an R value of approximately 4/5.

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REFERENCES


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COMMENTS ON THE PAPER BY A. ROBOCK 'ON THE EDDY STRUCTURE OF HURRICANES'

By J. S. A. GREEN

Robock's paper (Q.J., 101, pp. 657–663) is likely to give the impression that axially symmetrical circulations resembling hurricanes are impossible. Of course this is not so and modellers have produced symmetrical flows imitating hurricanes. A qualification of the argument presented is necessary.

On page 658 he states that the closed surface through which there is no mass flux can be deformed to coincide with a surface of constant angular momentum. For a symmetrical model of a hurricane this is not possible because the surfaces of constant angular momentum are not closed but open at the top and the proposed deformation cannot be achieved. What he does seem to show, therefore, is that real hurricanes are not dominated by axially symmetrical processes because their surfaces of constant angular velocity are not closed.

I suspect there remains some mystery about the argument which shows that there is no flux of angular momentum through a vertical wall. If air with greater tangential velocity flows towards the centre and air with lesser tangential velocity flows out there is an implied net flux of angular momentum towards the centre. Where is the fallacy?

I find the theme of the paper encouraging. It supports the views of those of us who visualize hurricanes as well as their embedded fields of cumulonimbus as organized systems. However, the explicit dynamics essentially remain unclear.

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ON THE EDDY STRUCTURE OF HURRICANES

By H. RIEHL

Robock (1975) takes the position that the existence of hurricanes from the standpoint of angular momentum must be maintained by non-steady 'eddy' terms rather than by a net ageostrophic mass circulation. There is a variant here, compared to somewhat older literature, in that this